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Wind energy integration into future energy systems based on conventional plants – The case study of Croatia

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HIGHLIGHTS

- Eight future energy scenarios in Croatia are analyzed with EnergyPLAN model.
- Future energy demand in Croatia is calculated with bottom-up model NeD.
- Influence of a high share of wind on load duration curve of large combustion plants is assessed.
- Influence of a high share of wind on critical excess of electricity in analyzed scenarios is assessed.

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ABSTRACT

Croatian energy system is currently highly import-dependent and integration of a high share of renewable energy sources needs to be considered. This paper studies eight scenarios; three proposed by the Croatian Energy Strategy, one proposed by the Indicative medium-term development plan of Croatia's Transmission System Operator, and four alternative scenarios that propose extensive construction of hydro, wind and solar power plants in Croatia. Calculations have been conducted in the EnergyPLAN model based on modeled long term energy demand projections in the NeD model, with 2009 as the base year and a scope ranging until the year 2030. Each of the eight proposed scenarios is observed through different hydrological conditions while analyzing import dependency, economic costs and CO_2 emissions. After the initial calculations, additional analysis of intensive wind power penetration has been conducted. The Results show that energy systems with a larger share of conventional and nonflexible power plants have more difficulty adjusting to wind power plants production. In case of a high share penetration of wind in a system based upon such power plants, the feasibility of investing in new large combustion plants that will spend most of the time working on minimum capacity is brought into question.

1. Introduction

Growing dependency on energy imports, obligation to decrease CO_2 emissions, high and unstable energy prices, and increasing age of production facilities are some of the problems European energy systems need to face. In 2010, primary energy import dependency of the EU-27 countries amounted to 52.7%, an increase of 22% since 1995, with predictions of reaching 70% in the next 20–30 years [1]. To decrease import dependency, as well as reduce CO_2 emissions, the European Union is planning increased implementation of renewable energy sources (RES), setting the goals of producing 20% of gross energy consumption from RES till 2020 [2] and 95% reduction of CO_2 emissions from the energy sector until 2050 [3].

In order to increase RES implementation and reduce CO_2 emissions, several different approaches have been studied by various papers. In article [4] several scenarios were considered in order to reduce CO_2 emissions in the UK by 60% till 2050. While some papers approach the problem in this way, considering the entire country [5], a number of them focus on small regions such as islands [6,7] and cities [8,9], as well as on particular sectors, such as energy [10], transport [11], residential [12] and industry, i.e. textile industry [13], steel industry [14] and cement industry [15]. Furthermore, some papers are going even further, exploring scenarios in order to achieve 100% RES system. Such papers have been published studying the cases of Denmark [16], Croatia [17], Portugal [18], Ireland [19] and Macedonia [20]. From all mentioned, we can conclude that a scenario approach is essential for successful

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planning of an energy system, as well as planning of long-term energy demand that has to be met by the system, explained in [21,22]. In that context, the implementation of RES has become an imperative after the *RE-thinking 2050* [3].

RE-thinking 2050 also calls for phase-out of fossil fuels, and while some of the EU members, like Denmark, have already implemented this goal into their energy strategies by aiming toward a 100% RES system [23], some of the member countries have not yet updated their energy strategies till 2050. However these energy strategies, such as Germany [24], Ireland [25], UK [26] and Portugal [27], still give a great emphasis on RES implementation. Significant implementation of RES has already begun – in 2008 more plants using renewable than conventional energy sources have been built, capacity-wise. Out of 23.8 GW of new power plant capacities, renewable energy sources accounted for 57%. Among the RES technologies used, wind power plants are leading by far. They have accounted for 39% of total installed power plants in 2009, followed by natural gas at 25%, and solar power plants with 17% of total installed capacities [3]. Due to rapid growth and intermittent nature of wind and solar energy, forecasting reliability of these systems will become prime concern [28]. Furthermore, the unstable characteristics of renewable energy sources lead to increase use in storage technologies such as pump hydro storage [17], compressed air energy storage (CAES) [29], electric vehicles [30] and batteries [31] for balancing electricity demand and supply.

In the case of Croatia, the Energy Strategy [32] acknowledges the need of RES implementation, with some projects already being realized [33], but there still remains much to be done in order to achieve goals set for the year 2020. Furthermore, the Croatian Energy Strategy predicts phase-out of all present thermal power plants, which use coal and heavy fuel oil, until 2030. In the case of hydro power plants, special attention must be given to hydrology since 51% of Croatia's energy production in 2009 came from large hydro power plants [34], with the yearly production in the last decade ranging from 39.4% in 2007 to 62.7% in 2010 of total energy production [35].

The purpose of this paper is to present a possible solution for development of future energy model for Croatia, taking into account future energy consumption, and to analyze implications of integrating a high share of intermittent renewable energy sources into future energy scenarios. First, a reference model for the year 2009 was created and future energy demand of Croatia in the years 2020 and 2030 has been calculated with NeD model. After creating the reference model, the models of eight future scenarios in the years 2020 and 2030 were developed and observed through different hydrological conditions, while analyzing electricity import, environmental and economic aspects. Three of those scenarios were proposed by the Croatian Energy Strategy [32], one was proposed by the Indicative medium-term development plan of Croatia's Transmission System Operator (TSO) [36], and four were alternative scenarios that propose extensive construction of hydro, wind and solar power plants in Croatia. Finally, the impacts of increased wind power production on critical excess electricity production, electricity import and load duration curves for condensing power plants in scenarios featuring extensive conventional power plants implementation were analyzed, thus highlighting advantages and disadvantages of proposed scenarios.

2. Methodology

2.1. EnergyPLAN model

In order to analyze and compare proposed scenarios, freeware EnergyPLAN model [37] has been selected. One of its advantages is its emphasis on renewable energy sources and their integration into existing systems. For example, the Chinese energy system was reconstructed in EnergyPLAN in paper [38]; a study of large-scale integration of wind power, phase-out of nuclear energy, while increasing the share of RES in the case of Romania, was analyzed in [39]; reduction of GHG emissions in the US using photovoltaic (PV) was studied in [40]; implementation of combined heat and power (CHP) plants was studied in [41], etc. As shown in the aforementioned papers, the model uses input data and conducts annual analysis of an energy system based on hourly steps.

Some of the input data used by the model are electricity and heat demands, installed capacities and technologies, fuel consumption divided by sectors, cost of fuel, investments and CO_2 emissions, operation and maintenance costs. Several regulation and optimization strategies, hourly curves describing various productions, import, export, market price changes, etc. are used, while allowing the user to set transfer capacities for the system allowing import and export of electricity. Results of the model analysis are electricity production, import and export along with their cost and gain respectively, emissions of CO_2 along with their breakdowns by technologies, expressed as annual, monthly or hourly values.

These results are greatly depending on the selected regulation strategy. Two main regulation strategies offered by the model are technical and market regulation. The technical regulation focuses on satisfying the given heat demand or both heat and electricity demand. It balances production from RES, hydro power plants, CHP, condensing, nuclear and other power plants in order to achieve given heat and electricity demand, while at the same time seeking to avoid or minimize critical excess electricity production (CEEP). CEEP is the amount of excess electricity produced that could not be used in the energy system or exported and it can lead to frequency changes and grid collapse. EnergyPLAN labels such energy as critical excess electricity production or CEEP. The market regulation option uses fuel prices, as well as market costs of electricity, in order to determine marginal production costs, and then determines optimum use of system components from an economic point of view. Detailed information about behavior and technology preferences for both regulation options are explained in the model's manual [42].

2.2. Future energy demand

Since the primary goal of an energy system is to satisfy the demand, long-term projections have to be made in order to properly design the future system.

Long-term projections used in this paper were modeled using the "bottom up" methodology, starting from the end energy consumer. Analysis and projections were based upon sector system approach in order to achieve better predictions of future energy demand. For the purposes of calculating long term energy demand NeD model was used [43]. This kind of approach demands a significant amount of information and a specific approach to each sector in order to accurately describe the mechanisms and parameters affecting the consumption in the sector, thus providing more accurate results. Referent year is used to calibrate and test the long term energy demand forecast methodology. That way all input information are checked and unknown components are determined, e.g. specific consumptions, various coefficients, etc. In order to use calculated data for system planning, it is necessary to convert the results from useful to final energy demand. This is achieved by combining data on various types of technologies and their efficiencies.

Future energy demand projections of Croatian sectors, using specific input data, have been studied in several papers. For instance, in case of the housing sector, described in [22], floor surfaces were combined with climate data and building